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LIMITING RANGE FOR MEDIUM-RANGE TARGET MODEL.(U)
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LIMITING RANGE FOR MEDIUM-RANGE TARGET MODEL

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LIMITING RANGE FOR MEDIUM-RANGE TARGET MODEL

by R. L. Mitchell
MRI Report 149-15
21 March 1978

Introduction

A medium-range target model was developed ~~in Reference 1, consisting~~ with ~~of~~ N point scatterers, where each scatterer can have an RCS that is aspect dependent. The medium-range constraint assumes that all scatterers on the target are in the linear region of the monopulse receive beam, and all scatterers are illuminated with a constant gain by the transmit beam. The purpose of this constraint is to remove the sensor pointing angles from the real-time computation. In other words, the signal that is generated on the RFSS array is independent of the sensor pointing angles. At shorter ranges where the transmit beam is no longer uniform *across the target*, or where the monopulse difference beam is not linear, the pointing angles of the sensor beam must be known so that the variable weighting can be implemented in the real-time simulation; moreover, the signals that would be received on each monopulse channel must be separately simulated and radiated into specific points on the receive beam so that each channel receives the proper signal and rejects the others.~~[1]~~

The purpose of this memo is to determine the minimum range for the applicability of the medium-range model. A simple Monte-Carlo simulation will be used to accomplish this.

The Target Model

A statistical type target model is assumed. Two scatterers are separated by an angle θ_T, in between N-2 scatterers are placed at random. Thus the

[1] "Design Requirements for Simulating Realistic RF Environment Signals on the RFSS," MRI Report 132-44, by R. L. Mitchell and I. P. Bottlik, dated 23 September 1977.

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target consists of N scatterers that cover an angular width of θ_T. All scatterers are assumed to be of equal RCS on the average, and each is fluctuated with a Rayleigh amplitude and random phase.

The Antenna Patterns

The sum channel two-way voltage antenna pattern is assumed to be

$$G_\Sigma(\theta) = 1 - \beta\theta^2 \tag{1}$$

and the two-way difference pattern

$$G_\Delta(\theta) = k(\theta - \alpha\theta^3) \tag{2}$$

Therefore, if the complex voltage is V_k on the kth scatterer at an angle θ_k, then the received voltages on the two channels are

$$V_\Sigma = \sum_k (1-\beta\theta_k^2)V_k \tag{3}$$

$$V_\Delta = k\sum_k (\theta_k - \alpha\theta_k^3)V_k \tag{4}$$

For the purpose of this investigation we have assumed

$$\alpha = 1.70/\theta_{3dB}^2 \tag{5}$$

$$\beta = 1.37/\theta_{3dB}^2 \tag{6}$$

where θ_{3dB} is the one-way half-power beamwidth. These values are typical of many tracking radars. The constant k will factor out of the problem later.

The Estimate of Angle

We assume that the boresite of the antenna is pointing exactly at the center of the target (midway between the end points). The estimate of angle is assumed to be

$$\hat{\theta}_{ACT} = \frac{1}{k} \mathrm{Re}\{V_\Delta / V_\Sigma\} \tag{7}$$

where the subscript ACT denotes the actual (assumed) target, in contrast to an approximate one based on the medium range model.

The Medium-Range Model

A glint centroid will be calculated for the target that is based on $G_\Sigma(\theta) = 1$ and $G_\Delta(\theta) = \theta$. Thus the compostive signal

$$V' = \sum_k V_k \tag{8}$$

will be radiated from the angle

$$\theta' = \mathrm{Re}\left\{\frac{1}{V'} \sum_k \theta_k V_k\right\} \tag{9}$$

Now if we use the antenna patterns in (1) and (2), and the formula for the estimate of the angle, we have

$$\hat{\theta}_{APP} = \theta' \frac{1-\alpha(\theta')^2}{1-\beta(\theta')^2} \tag{10}$$

Thus we will compare $\hat{\theta}_{APP}$ with $\hat{\theta}_{ACT}$ to determine where the medium range model breaks down.

Results

In Tables 1 through 6 we show the results of 20 statistical replications of a target consisting of N=5 scatterers, where the target width varies from

θ_T/θ_{3dB} = .25 to 1.50 (the glint angles $\hat{\theta}_{ACT}$ and $\hat{\theta}_{APP}$ are designated as ACTUAL and APPROX, each being normalized to the half-power width). For a target width of 25% of the beamwidth (Table 1) the peak error is .003 (or .3% of the beamwidth), which is negligible. For a target width of 50% of the beamwdith (Table 2) the peak error is over 100% of the beamwidth (REP 20); however, the actual glint for this case is also large, amounting to 66% of the beamwidth. In practice, we can tolerate a large error if the glint angle is also large. It is more important to keep the errors small when the glint angles are small. Thus REP 12 in Table 2 represents probably the most severe error, which is 2.8% of the beamwidth when the actual glint is 14% of the beamwidth.

If we rule out those replications where the actual glint is larger than half of the target width, we can construct the following table

Target Width	Peak Error
.25	.002
.50	.028
.75	.076
1.00	.184

All of these errors are negligible. However, when we go to a target of width $1.25\theta_{3dB}$ (Table 5) we observe several large errors, even when the actual glint is small. For example, on REP 16 the actual glint is only 7.7% of the beamwidth, but the error is over 2 beamwidths. Clearly, the model breaks down for $\theta_T = 1.25\theta_{3dB}$. The actual point at which the model breaks down lies somewhere between $\theta_T = 1.00\theta_{3dB}$ and $\theta_T = 1.25\theta_{3dB}$. Variations in the antenna patterns and formulas for measuring angle will impact on a precise determination of where the model breaks down, but we can state conservatively that the model is valid as long as $\theta_T \leq \theta_{3dB}$.

In order to test the effect of the number of scatterers in the model, we repeated the previous simulation for N=10. The results are shown in Tables 7 through 12. No major discrepancies are noted from the previous conclusions.

Table 1. Comparison of Actual Target with Medium-Range Model (APPROX) for $\theta_T/\theta_{3dB} = 0.25$ (N=5, all angles normalized to θ_{3dB})

REP	ACTUAL	APPROX	DIFF	.......SCATTERER	LOCATION.......			
1	.051	.051	-.000	-.125	.020	.072	.113	.125
2	-.057	-.058	-.001	-.125	-.123	-.051	-.012	.125
3	.043	.043	.000	-.125	-.056	-.049	.047	.125
4	-.074	-.073	.001	-.125	-.092	-.029	.083	.125
5	-.175	-.178	-.003	-.125	-.100	-.056	.021	.125
6	.167	.165	-.001	-.125	-.104	.030	.123	.125
7	.168	.169	.001	-.125	.048	.109	.120	.125
8	.002	.002	-.000	-.125	-.092	-.072	.091	.125
9	.015	.015	.000	-.125	-.120	.010	.080	.125
10	-.018	-.019	-.000	-.125	-.046	.066	.110	.125
11	.041	.041	.000	-.125	-.053	.021	.101	.125
12	.095	.096	.001	-.125	-.026	-.001	.097	.125
13	-.045	-.047	-.002	-.125	.024	.093	.108	.125
14	.085	.085	.000	-.125	-.073	-.009	.097	.125
15	-.069	-.071	-.002	-.125	-.013	-.011	.032	.125
16	-.035	-.034	.001	-.125	-.066	.023	.066	.125
17	.077	.077	-.000	-.125	-.014	-.001	.105	.125
18	-.109	-.110	-.001	-.125	-.087	-.072	.083	.125
19	.113	.114	.000	-.125	.044	.087	.107	.125
20	-.006	-.006	.000	-.125	-.062	-.055	-.035	.125

Table 2. Comparison of Actual Target with Medium-Range Model (APPROX) for $\theta_T/\theta_{3dB} = 0.50$ (N=5, all angles normalized to θ_{3dB})

REP	ACTUAL	APPROX	DIFF	.......SCATTERER	LOCATION.......			
1	-.096	-.102	-.006	-.250	-.203	-.094	-.061	.250
2	-.042	-.054	-.011	-.250	.005	.075	.083	.250
3	-.220	-.208	.012	-.250	-.192	-.158	-.057	.250
4	.122	.126	.004	-.250	.105	.111	.176	.250
5	-.940	-1.774	-.835	-.250	-.242	-.214	.071	.250
6	-.459	-.445	.014	-.250	-.056	-.039	.227	.250
7	-.172	-.171	.001	-.250	-.212	.052	.199	.250
8	.116	.110	-.006	-.250	.036	.038	.204	.250
9	-.263	-.277	-.014	-.250	-.189	.045	.142	.250
10	.057	.063	.006	-.250	-.133	-.111	-.024	.250
11	.047	.044	-.003	-.250	-.181	.062	.152	.250
12	.141	.113	-.028	-.250	.008	.067	.120	.250
13	.088	.087	-.001	-.250	.004	.101	.124	.250
14	.031	.036	.004	-.250	-.096	-.007	.031	.250
15	-.666	-.400	.266	-.250	-.229	.150	.188	.250
16	.381	.364	-.017	-.250	.177	.177	.199	.250
17	-.305	-.284	.021	-.250	-.149	.001	.094	.250
18	.032	.040	.008	-.250	-.158	-.101	.179	.250
19	.075	.076	.001	-.250	-.189	-.141	.156	.250
20	.662	1.777	1.115	-.250	.018	.039	.227	.250

Table 3. Comparison of Actual Target with Medium-Range Model (APPROX) for θ_T/θ_{3dB} = .75 (N=5, all angles normalized to θ_{3dB})

REP	ACTUAL	APPROX	DIFF	.......SCATTERER	LOCATION.......			
1	-.981	-1.775	-.794	-.375	-.103	.108	.173	.375
2	-.470	-.454	.016	-.375	-.087	.004	.290	.375
3	.186	.171	-.015	-.375	-.278	.198	.286	.375
4	.258	.284	.025	-.375	-.319	.199	.312	.375
5	.317	.331	.013	-.375	.005	.016	.199	.375
6	.345	.346	.001	-.375	.314	.339	.343	.375
7	.675	.443	-.232	-.375	-.134	.188	.228	.375
8	.154	.181	.027	-.375	-.112	.252	.309	.375
9	.223	.253	.030	-.375	-.031	.032	.226	.375
10	-.168	-.180	-.013	-.375	-.154	-.118	.276	.375
11	.235	.311	.076	-.375	-.339	-.233	.150	.375
12	.201	.214	.013	-.375	-.325	-.311	.180	.375
13	.163	.172	.010	-.375	-.295	-.006	.022	.375
14	-.023	-.013	.009	-.375	-.348	-.236	-.096	.375
15	-.103	-.113	-.010	-.375	.092	.146	.315	.375
16	.435	.438	.003	-.375	.072	.334	.342	.375
17	.040	.045	.004	-.375	-.197	-.122	.018	.375
18	1.826	8.418	6.592	-.375	-.064	.067	.096	.375
19	.114	.151	.036	-.375	-.232	-.041	.128	.375
20	.261	.291	.030	-.375	.017	.077	.079	.375

Table 4. Comparison of Actual Target with Medium-Range Model (APPROX) for θ_T/θ_{3dB} = 1.00 (N=5, all angles normalized to θ_{3dB})

REP	ACTUAL	APPROX	DIFF	.......SCATTERER	LOCATION.......			
1	-.170	-.128	.042	-.500	-.352	-.230	.350	.500
2	.129	.174	.044	-.500	-.194	-.122	.005	.500
3	.288	.336	.048	-.500	-.319	-.237	.316	.500
4	.172	.356	.184	-.500	-.497	-.198	.481	.500
5	-.289	-.277	.012	-.500	-.448	-.282	-.207	.500
6	-.247	-.300	-.053	-.500	-.395	.024	.037	.500
7	.230	.182	-.048	-.500	-.454	.090	.247	.500
8	-.438	-.437	.001	-.500	-.434	-.424	-.091	.500
9	-.114	-.252	-.138	-.500	-.096	-.058	.295	.500
10	1.003	1.775	.772	-.500	-.088	-.061	.259	.500
11	.221	.216	-.005	-.500	-.380	.057	.112	.500
12	.569	.071	-.499	-.500	-.299	.154	.227	.500
13	-.018	-.004	.015	-.500	-.410	-.150	.438	.500
14	.352	.221	-.130	-.500	-.221	-.052	.492	.500
15	.149	.098	-.050	-.500	-.346	-.313	.180	.500
16	-.397	-.326	.071	-.500	-.377	.295	.455	.500
17	-.341	-.369	-.028	-.500	-.476	-.078	.178	.500
18	-.116	-.097	.020	-.500	-.466	-.226	.081	.500
19	.264	.363	.099	-.500	-.336	-.294	.098	.500
20	.398	.416	.018	-.500	-.161	-.152	.309	.500

Table 5. Comparison of Actual Target with Medium-Range Model (APPROX) for θ_T/θ_{3dB} = 1.25 (N=5, all angles normalized to θ_{3dB})

REP	ACTUAL	APPROX	DIFF	.......SCATTERER LOCATION.......				
1	-.315	-.332	-.017	-.625	-.549	-.540	-.369	.625
2	-.217	-.079	.138	-.625	-.453	-.304	.399	.625
3	1.017	-2.253	-3.271	-.625	-.558	-.303	-.230	.625
4	.229	.245	.016	-.625	-.549	.170	.410	.625
5	.038	-.007	-.045	-.625	-.240	.028	.241	.625
6	.459	.257	-.202	-.625	-.227	.348	.516	.625
7	-.118	-.032	.086	-.625	-.220	-.062	.110	.625
8	-.394	-1.867	-1.473	-.625	-.573	-.105	.085	.625
9	-.054	-.089	-.036	-.625	-.524	.033	.192	.625
10	.535	3.309	2.774	-.625	.136	.188	.561	.625
11	.496	.241	-.255	-.625	.158	.508	.553	.625
12	.222	-.131	-.352	-.625	-.211	.286	.466	.625
13	-.429	1.867	2.296	-.625	-.363	-.135	.105	.625
14	-.051	.216	.267	-.625	-.211	-.098	.439	.625
15	.005	.152	.147	-.625	-.253	-.173	.082	.625
16	.077	2.483	2.406	-.625	-.205	.024	.550	.625
17	-1.712	-.279	1.433	-.625	-.150	.068	.156	.625
18	-.400	-.453	-.053	-.625	-.377	-.302	-.271	.625
19	.010	.018	.007	-.625	-.032	.028	.605	.625
20	-.260	-.384	-.124	-.625	-.584	-.216	-.073	.625

Table 6. Comparison of Actual Target with Medium-Range Model (APPROX) for θ_T/θ_{3dB} = 1.50 (N=5, all angles normalized to θ_{3dB})

REP	ACTUAL	APPROX	DIFF	.......SCATTERER LOCATION.......				
1	.476	-.155	-.631	-.750	-.294	.204	.466	.750
2	.139	-.236	-.375	-.750	-.634	-.299	.029	.750
3	-.091	14.613	14.704	-.750	-.542	-.200	.463	.750
4	-.093	2.506	2.598	-.750	-.518	-.348	.004	.750
5	-.138	-.129	.009	-.750	-.544	-.352	-.030	.750
6	.034	-.245	-.280	-.750	-.637	-.264	.575	.750
7	-.064	.343	.407	-.750	-.296	.097	.380	.750
8	-1.985	-.294	1.691	-.750	-.510	.558	.618	.750
9	.090	-.026	-.117	-.750	-.264	-.009	.398	.750
10	.229	-.016	-.245	-.750	-.309	.302	.347	.750
11	-.351	1.839	2.190	-.750	-.471	-.379	.746	.750
12	-.160	.288	.448	-.750	-.302	.676	.683	.750
13	-.396	-2.593	-2.198	-.750	-.548	.535	.598	.750
14	.261	1.782	1.521	-.750	-.641	-.018	.679	.750
15	.155	1.781	1.626	-.750	-.686	.555	.704	.750
16	.982	-8.846	-9.829	-.750	-.691	-.147	.341	.750
17	-.028	1.826	1.854	-.750	-.266	-.232	.749	.750
18	.023	-.221	-.244	-.750	-.743	-.295	.678	.750
19	-.005	.433	.438	-.750	-.708	-.016	.748	.750
20	-.352	-.301	.051	-.750	-.479	.386	.740	.750

Table 7. Comparison of Actual Target with Medium-Range Model (APPROX) for θ_T/θ_{3dB} = .25 (N=10, all angles normalized to θ_{3dB})

REP	ACTUAL	APPROX	DIFF
1	.014	.014	.001
2	.033	.033	.000
3	-.029	-.029	.000
4	.042	.042	-.000
5	.032	.031	-.001
6	-.007	-.007	.000
7	-.000	-.000	-.000
8	-.014	-.006	.007
9	.010	.010	-.000
10	-.092	-.096	-.003
11	-.023	-.023	.000
12	.139	.138	-.001
13	.046	.047	.001
14	.042	.042	.000
15	-.055	-.057	-.001
16	.018	.019	.001
17	.003	.003	-.000
18	-.118	-.117	.000
19	-.136	-.139	-.003
20	-.056	-.058	-.002

Table 8. Comparison of Actual Target with Medium-Range Model (APPROX) for θ_T/θ_{3dB} = .50 (N=10, all angles normalized to θ_{3dB})

REP	ACTUAL	APPROX	DIFF
1	.049	.060	.011
2	.040	.048	.008
3	.167	.178	.011
4	.242	.272	.030
5	.177	.191	.014
6	.042	.042	-.000
7	-.110	-.108	.002
8	-.038	-.045	-.006
9	.032	.037	.005
10	1.030	1.792	.762
11	-.039	-.049	-.009
12	.111	.122	.010
13	-.156	-.147	.009
14	.161	.167	.006
15	-.052	-.055	-.002
16	-.206	-.218	-.012
17	.028	.027	-.001
18	-.217	-.208	.009
19	-.095	-.098	-.004
20	-.121	-.103	.018

Table 9. Comparison of Actual Target with Medium-Range Model (APPROX) for θ_T/θ_{3dB} = .75 (N=10, all angles normalized to θ_{3dB})

REP	ACTUAL	APPROX	DIFF
1	-.049	-.043	.006
2	.017	.000	-.016
3	.022	.026	.004
4	-.141	-.142	-.001
5	.542	.451	-.092
6	-.083	-.111	-.028
7	.021	.023	.002
8	.226	.108	-.118
9	1.156	1.825	.669
10	.188	.224	.036
11	-.043	-.043	.000
12	.282	.356	.074
13	.055	.053	-.001
14	.119	.093	-.026
15	.192	.228	.036
16	-.232	-.303	-.072
17	.587	.036	-.551
18	.247	.291	.043
19	.036	.031	-.005
20	-.309	-.299	.010

Table 10. Comparison of Actual Target with Medium-Range Model (APPROX) for θ_T/θ_{3dB} = 1.00 (N=10, all angles normalized to θ_{3dB})

REP	ACTUAL	APPROX	DIFF
1	-.045	-.096	-.051
2	.048	.068	.020
3	-.013	.003	.016
4	.681	2.162	1.481
5	-.426	-.442	-.016
6	.327	.364	.037
7	-.045	-.128	-.083
8	.129	.232	.103
9	-.411	-.458	-.047
10	.055	.077	.022
11	-.173	-.073	.100
12	.143	.124	-.019
13	.292	.391	.099
14	-.109	-.154	-.045
15	.224	.314	.090
16	-.201	-.227	-.025
17	.462	.459	-.003
18	-.346	-.366	-.020
19	.203	.414	.211
20	-.036	-.021	.015

Table 11. Comparison of Actual Target with Medium-Range Model (APPROX) for θ_T/θ_{3dB} = 1.25 (N-10, all angles normalized to θ_{3dB})

REP	ACTUAL	APPROX	DIFF
1	-.220	-.220	-.001
2	.368	.402	.034
3	-.271	-.365	-.094
4	.077	.138	.061
5	.187	-.258	-.445
6	-.184	-.455	-.271
7	.027	1.922	1.895
8	-.006	-.082	-.076
9	-.284	-.356	-.072
10	-.155	-.233	-.078
11	-.811	-2.001	-1.190
12	-.229	-.277	-.048
13	.248	.216	-.032
14	.041	-.025	-.065
15	-.363	-.431	-.069
16	-.070	-.177	-.107
17	-.675	-3.174	-2.499
18	-.136	.441	.577
19	-.058	-.167	-.108
20	.375	.357	-.018

Table 12. Comparison of Actual Target with Medium-Range Model (APPROX) for θ_T/θ_{3dB} = 1.50 (N=10, all angles normalized to θ_{3dB})

REP	ACTUAL	APPROX	DIFF
1	.153	.418	.265
2	.053	.156	.103
3	.800	.431	-.369
4	.242	.456	.214
5	-.165	.170	.335
6	.068	-.269	-.337
7	-.222	-.439	-.217
8	.155	.452	.297
9	.048	-.254	-.302
10	.017	.284	.268
11	.863	.095	-.768
12	.006	-2.603	-2.609
13	.179	-.085	-.263
14	.006	-.173	-.179
15	-.003	.145	.148
16	-.305	-1.774	-1.470
17	.019	-.447	-.466
18	.057	.213	.156
19	-.044	-.380	-.336
20	.140	.204	.064